An Analysis of Strength Training Implementation in Ballet

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Abstract

Ballet, a style of dance that is known for its 180-degree external rotation, extreme precision, discipline, and aesthetics, is an athletic activity that is undertaken by many young people, particularly females. Although ballet has many athletic components, recent studies have shown there are a variety of weaknesses that impact its participants, including the female athlete triad, lack of lower extremity muscular strength, risk of injury, and overtraining. According to recent research, strength training, although not historically paired with ballet, could minimize ballet dancers' deficiencies by increasing muscular strength and reducing risk of injury and incidence of the female athlete triad. The purpose of this thesis is to analyze the summation of research findings pertaining to the benefits and weaknesses of ballet and how strength training may be optimally integrated into the training program of ballet dancers.

An Analysis of Strength Training Implementation in Ballet

Introduction

Physical Fitness

Movement is an experience common to all of mankind. The way that humans move is unlike any other creature on earth. The human body was designed for movement and naturally knows how to move in an efficient manner. Furthermore, as the human body moves, its musculature is engaged and strengthened to support movement. Physical fitness is broadly known as the character traits needed for an individual to complete various physical activity endeavors (Wilder et al., 2006). Health-related physical fitness, a type of physical fitness focused on the promotion of overall health and prevention of diseases caused by physical inactivity, compiles five different categories: body composition, cardiorespiratory endurance, muscular strength, muscular endurance, and flexibility. Health-related physical fitness can be contrasted with skill-related physical fitness. The components of skill-related physical fitness include coordination, balance, agility, speed, reaction time, and power (Bushman, 2017). Although beneficial for all age groups, combining all aspects of health-related and skill-related physical fitness is a particular goal for the athletic population.

Ballet

Dance is an artistic and athletic activity that is undertaken by many people. Although there are many versions and styles of dance, perhaps the most difficult and precise style is known as ballet. In ballet, dancers seek to execute movements with nearly 180-degree lower extremity external rotation (Biernacki et al., 2018). Discipline, precision, extreme flexibility, aesthetics, and elegance are all paramount in ballet, particularly for females. Once female ballet dancers have gained the experience and strength needed, they transition to dancing “on pointe”, wearing ballet shoes with hard boxes at the tips of the toes to give support to the tips of the toes as they bear the full weight of the dancer. Professional ballerinas train daily by taking various technique classes and participating in rehearsals for their upcoming performances. This training can total anywhere from 20 to 39 hours per week and potentially even greater if performances are included (Bronner et al., 2008; Gamboa et al., 2008).

Strength Training

Another form of exercise that is common among the athletic population due to its perceived benefits is strength training (ST). ST, also known as resistance training, focuses on building muscle strength using resistance against the muscles. Dumbbells, barbells, resistance bands, or even using one's bodyweight against gravity can all be methods of incorporating resistance. Studies reveal that many ballet dancers have not utilized ST in their typical training regimes (Farmer & Brouner, 2021; Stracciolini et al., 2016); however, the implementation of ST into ballet training can improve some of the weaknesses that are often found in dancers, prevent common ballet injuries, improve certain technical aspects of ballet, and prevent incidence of the female athlete triad: amenorrhea, disordered eating, and low bone mineral density (Koutedakis & Jamurtas, 2004).

Thesis Purpose

Due to the rigidity of ballet training, supplemental training is not currently encouraged or seen as essential to the health and fitness of the ballet dancer (Koutedakis & Jamurtas, 2004). Research has only just begun to discover the need for supplemental training in ballet in the past decade. Through a thorough analysis of the strengths and weaknesses of both ballet and ST individually, all aspects and concerns of implementing ST into ballet can be considered. The purpose of this thesis is to analyze the summation of research findings pertaining to the benefits and weaknesses of ballet and how strength training may be optimally integrated into the training program of ballet dancers.

Aspects of Ballet

Benefits of Ballet

Flexibility

When considering ballet as a type of physical activity that requires great athletic ability and physical fitness, many beneficial aspects are inherent to this activity. Perhaps the most apparent of which is the extreme amount of flexibility needed to execute many ballet movements. Flexibility refers to the range of motion present in the structures around a joint, including tendons, ligaments, and muscles (Wilder et al., 2006). According to a study by McCormack, et al. (2004), the flexibility needed for professional ballet dancers has led to generalized joint hypermobility in up to 72% of participants, depending on level of training, gender, and age. This percentage is considerably higher than the approximate 5% prevalence in the generalized population (McCormack et al., 2004). Dramatically increased flexibility is advantageous to ballet dancers, as it allows them to execute the correct aesthetics the activity requires (Phan et al., 2020). Many ballet movements necessitate flexibility to properly execute.

Skill-related Physical Fitness

Another beneficial aspect of ballet is the way in which it enhances nearly all aspects of skill-related physical fitness. Skill-related physical fitness is comprised of coordination, balance, agility, speed, reaction time, and power (Bushman, 2017). In ballet, skill acquisition is prioritized from a young age. Ballet dancers tend to see themselves more as artists as opposed to athletes and, thus, focus heavily on honing the skill of their art beginning in childhood (Allen & Wyon, 2008). Movements in ballet often require dancers to balance on one leg and coordinate each limb to perform different movements simultaneously. Additionally, movements in ballet such as frappé, saut de chat, as well as various other jumps and turns require the dancer to move explosively, creating a great amount of power. In general, ballet is an activity that requires a great amount of speed, strength, and coordination (Kalichová, 2011). Because ballet places an emphasis on the majority of the aspects of skill-related physical fitness, a beneficial component of ballet is the development of skill-related physical fitness.

Artistry

In addition to the beneficial aspects of flexibility and skill-related physical fitness, ballet dancers are set apart from other athletes in their emphasis on artistry and creativity. It is well-known that ballet is primarily an artistic activity. In the studio, the emphasis is clearly placed on developing one's artistry and the tools to enhance that component. Many ballet dancers are incredibly focused on this aspect of ballet from a young age (Allen & Wyon, 2008). The artistry and creativity prioritized in ballet sets it apart from other athletic activities. Ballet dancers are allowed more room to express their own artistry than athletes in other sports.

Weaknesses of Ballet

The Female Athlete Triad

Since ballet is primarily an artistic activity which requires a high level of athletic ability, there are many areas in which ballet is not sufficient to develop a well-rounded athlete. Because there is such a great emphasis on artistry, there are other physiological areas that are consequently underemphasized. Perhaps the most concerning weakness of ballet lies in its high incidence of the female athlete triad (Koutedakis & Jamurtas, 2004). The female athlete triad is known as the linkage of amenorrhea, low bone mineral density, and disordered eating (Koutedakis & Jamurtas, 2004). This linkage is detrimental to females, particularly younger female athletes who are still developing physically. Although the presence of only one or two aspects of the female athlete triad leaves females susceptible to the triad as a whole, all three aspects of the female athlete triad can be observed in female ballet dancers.

Bone Mineral Density

The first component of the female athlete triad that is visible in ballet dancers is low bone mineral density. Koutedakis and Jamurtas (2004) found that bone mineral density was at normal or slightly elevated levels at weight-bearing sites. However, they also found levels of bone mineral density to be reduced at non-weight bearing sites. Wewege and Ward (2018) found that there is an osteogenic effect on certain sites of the body. Additionally, they noted a particularly reduced bone mineral density value in the upper extremities of adolescent ballet dancers as compared with non-dancer controls of the same age. In a study performed by Doyle-Lucas et al. (2010), researchers assessed aspects of the female athlete triad including low bone mineral density in professional ballet dancers. They found that 6 of the 15 subjects met each of the criteria, including low bone mineral density, for the female athlete triad. In addition to these studies, literature exists which does not support the hypothesis that ballet dancers suffer from low bone mineral density. In a systematic review by Amorim et al. (2015), 35 studies regarding bone mineral density in dancers were screened. The results ultimately were heterogenous, and the authors expressed the need for more quality research on the topic. A systematic review by Hincapié and Cassidy (2010) found similarly that data regarding bone mineral density in female ballet dancers produced mixed results. They concluded, however, that the issue remains highly important to consider and should not be dismissed. Research performed by Koutedakis and Jamurtas (2004) and Wewege and Ward (2018) indicates that young female ballet dancers likely demonstrate reduced bone mineral density at least in the upper extremity and at non-weight bearing sites. Koutedakis and Jamurtas (2004) noted an uncertainty whether dancers would be able to recover normal bone mineral density levels even at the end of their dance careers. Given the fact that peak bone mineral density often is reached between the ages of 20 and 30, this concern is valid and poses an increased risk of osteoporosis in the future for female ballet dancers (Lu et al., 2016). Koutedakis and Jamurtas (2004) additionally postulated that intense ballet training results in both high levels of cortisol, a hormone produced when experiencing stress, and reduced insulin growth factor which could both negatively impact the growth of trabecular bone.

Disordered Eating

The second component of the female athlete triad is disordered eating. Major categories of disordered eating include anorexia nervosa, bulimia, and eating disorders not otherwise specified (EDNOS) (Arcelus et al., 2014). In a systematic review performed by Arcelus et al. (2014), ballet dancers were compared with dancers of all types as well as non-dancers. The researchers found that ballet dancers were three times more likely to develop disordered eating, specifically anorexia or EDNOS, when compared to non-dancers. When compared to all dancers, ballet dancers demonstrated higher prevalence of anorexia and EDNOS. This indicates that even among dancers, ballet dancers are at a higher risk for most types of disordered eating. A systematic review by Hincapié and Cassidy (2010) determined that the lifetime prevalence of disordered eating in professional ballet dancers was 50%. This is likely due to the highly desired body type and body composition that are heavily encouraged in the ballet community. Specific personality traits have also been linked to the development of disordered eating. High levels of perfectionism and low self-esteem that are two personality traits that are both linked to disordered eating as well as very common among young female ballet dancers (Arcelus et al., 2014).

Koutedakis and Jamurtas (2004) found that ballet dancers often desire to reduce their body mass regardless of their current status. This desire is most drastic and prevalent in ballet dancers between the ages of 11 and 13. The researchers also noted that dancers of all age categories desire a body mass in the 5th percentile or lower. This desire for dangerously low body mass often drives ballet dancers to disordered eating and generally low energy intake. Ballet students often consume only 70% of recommended energy intake, and professional ballet dancers are only slightly higher, consuming 80% of recommended energy intake (Koutedakis & Jamurtas, 2004). This reduced energy intake has been linked to a significantly reduced resting metabolic rate, both absolute and relative to dancers' fat-free mass (Doyle-Lucas et al., 2010). It should be noted that there are several health risks related to disordered eating and the low energy intake seen in ballet dancers. Benson et al. (1989) found that low energy intake is linked with an increased risk of injury in ballet dancers. Koutedakis and Jamurtas (2004) asserted that dancers seek a body fat percentage between 16-18% or lower, however, as a result of dancers' low energy intake, they often induce amenorrhea, the third component of the female athlete triad.

Amenorrhea

The third component of the female athlete triad is amenorrhea. Amenorrhea is a menstrual abnormality and can present as either primary or secondary amenorrhea (Brown et al., 2017). Primary amenorrhea is the absence of menarche by the age of 15 when other secondary sex characteristics are present and can also also present as the lack of menarche 2.5 years after the development of other secondary sex characteristics. Secondary amenorrhea is the absence of regular menstruation for 3 cycles or the absence of irregular menstruation for 6 months in females who have previously reached menarche (Brown et al., 2017). Another menstrual abnormality, oligomenorrhea, refers to cycles longer than 35 days (Brown et al., 2017). A study by Stokić et al. (2005) found a significant reduction in the body fat percentage and body mass index (BMI) in female ballet dancers when compared to non-dancers. The researchers also found that amenorrhea and oligomenorrhea were present in 20% and 10% of ballet dancers, respectively, whereas such menstrual irregularities were not present in any of their non-dancer counterparts. Ballet dancers additionally were found to have a significantly later onset of menarche. In a research study by Witkoś and Wróbel (2019), a direct correlation was found between the number of hours spent in training and an increase in the prevalence of menstrual disorders in amateur ballet dancers. Additionally, as the number of training hours increased, the longer the break between menstrual cycles was also identified.

When a young ballet dancer experiences such a vigorous training regimen with such low body fat percentage and such low energy availability, changes in hormones will cause the dancer to experience secondary amenorrhea (Witkoś & Wróbel, 2019). These hormonal changes and their respective effects are described by Witkoś and Wróbel (2019). Adipose tissue, commonly known as body fat, is responsible for the metabolism of androgens into oestrogens which are ultimately responsible for the proper function of the hypothalamic-pituitary-gonadal (HPG) axis. The HPG axis, comprised of the hypothalamus, pituitary gland, and the gonads, refers to the coordination among the three anatomical structures in the body and is responsible for hormone production and regulation associated with puberty. When dancers are unable to maintain a proper amount of adipose tissue through excessive training and low energy intake, the function of the HPG axis is inhibited. During puberty, ballet dancers experience an increase in the function of the HPG axis. The hypothalamus and pituitary gland also increase production of gonadoliberin, luteinising hormone, and follicle-stimulating hormone. However, ballet dancers often also experience a dramatic increase in training. When there is not enough adipose tissue to support the function of the still-developing HPG axis, its function is inhibited. It is unable to produce adequate levels of luteinizing hormone and follicle-stimulating hormone. As a result, the luteal phase of the menstrual cycle disappears, and the follicular phase lengthens. Progesterone and estradiol levels also decrease as a result. These hormonal changes lead to menstrual disorders in young female ballet dancers.

Lack of Cardiorespiratory Fitness

In addition to the presence of the female athlete triad in ballet dancers, another weakness of ballet is the lack of emphasis on cardiorespiratory endurance. Cardiorespiratory endurance is known at the ability of the heart and lungs to fuel the movement of muscles through the transport and usage of oxygen, and it is often used as a prominent marker of overall health-related physical fitness (Cheng et al., 2019). Ballet is known as an intermittent activity, most similar to soccer or tennis, in which shorter bursts of energy are required. In an activity with intermittent movement, the aerobic energy system is engaged to a much smaller degree. As a result, positive adaptations to the cardiovascular demands are questionable. A variety of studies have assessed the VO_2max of professional ballet dancers. VO_2max refers to the maximal amount of oxygen that the body is able to utilize during exercise, and it is used as a measure of one's aerobic capacity (Oreb et al., 2006). Although initial studies found a VO_2max comparable to that of a sedentary individual, researchers agrees that the mean VO_2max of female professional ballet dancers falls within the range of 50.22 $\pm$ 12.6 ml/kg/min (Oreb et al., 2006; Twitchett et al., 2009). This value is significantly higher than the mean VO_2max of sedentary individuals and indicates that there are significant positive adaptations seen in the cardiovascular system as a result of ballet (Twitchett et al., 2009). An additional distinction in VO_2max can be made in a ballet dancer's role in the ballet company. Principal ballet dancers, the dancers with the largest, longest, and most technical roles, demonstrate mean VO_2maxes of 49.04$\pm$3.63 ml/kg/min which exceeds that of soloists (43.38$\pm$7.14) (Wyon et al., 2007). Additionally, researchers have noted a significant difference in VO_2 demands between the daily ballet technique class and a ballet performance (Schantz & Astrand, 1984). Ballet class is split into three main categories, each with different metabolic demands. These three categories are barre exercises, center exercises of moderate intensity, and center exercises of high intensity. Barre exercises, performed at the beginning of class, allow dancers to focus on technique by providing a barre that the dancer uses to maintain balance and stability while standing on one leg. Center exercises of moderate intensity are mainly comprised of similar movements as seen at barre and challenge the dancer to maintain balance while eliminating the stability of the barre; center exercises of high intensity often include faster-paced combinations, jumps, and more travelling across the floor. It has been demonstrated that dancers utilize 36%, 43%, and 46% of their VO_2max for each category, respectively (Schantz & Astrand, 1984). However, in studio performances, ballet dancers average 80% VO_2max and when performing in front of a live audience, their VO_2max averages 85% (Schantz & Astrand, 1984). Although these levels are maintained for the duration of each performance or piece, this time is not sufficient to create any positive cardiorespiratory adaptations. Ballet dancers' cardiorespiratory systems may not be adequately prepared for performance since the cardiorespiratory demands of ballet class fall short of what is needed for ballet performances (Twitchett et al., 2009).

Overtraining

An additional weakness of ballet is the tendency towards overtraining. Ballet dancers are encouraged to focus on skill acquisition to attain better overall technique. This endeavor often requires dancers to work year-round at a high level. Consequentially, a feeling of "burn-out" or overtraining is common and ever-increasing (Farmer & Brouner, 2021; Koutedakis, 2000). A study by Koutedakis et al. (1999) found that ballet dancers' fitness levels increased following a holiday period, indicating that the dancers were in an overtrained state prior to the holiday period. They postulated that a 6-week summer break can aid in recovery from overtraining (Koutedakis et al., 1999). However, in recent years, ballet culture has emphasized the importance of a summer intensive ballet program for young ballet dancers seeking to improve their technique in the off season. This emphasis contradicts the literature in regard to the concern of overtraining in ballet dancers (Koutedakis et al., 1999).

Similar to the concept of overtraining, ballet dancers also lack periodization throughout the year. Periodization is the method in which volume, frequency, and intensity of exercise can be manipulated to help the athlete optimize performance ability at a given time (Wyon, 2010). It has been integrated into the training for nearly all sports. Whereas many athletes taper, or reduce overall training, just prior to their competition, ballet dancers often increase rehearsal time and training (Wyon, 2010). This increase in volume paired with dancers' lack of physical fitness causes dancers to feel a high amount of fatigue (Wyon, 2010). The lack of periodization seen in ballet is unlike any other sport or athletic endeavor.

Common Injuries

Another weakness of ballet is the prevalence of injury. Koutedakis et al. (1997) reported that over a 12-month period, over 50% of professional ballet dancers experienced injury and took

1-6 days off of exercise due to injury. Injury to the lower back and lower extremity comprised 90% of the injuries experienced (Koutedakis et al., 1997). Overuse injuries in the lower extremity are the most common injuries in ballet dancers (Yau et al., 2017). Khan et al. (1995) found that lower extremity injury is the most common site of injury in ballet dancers, the most prevalent being injury to the first metatarsophalangeal joint, stress fractures in the second metatarsal, ankle impingement syndrome, flexor hallucis longus tendinitis, compartment syndrome in the shins, and patellofemoral syndrome. A systematic review by Biernacki et al. (2018) found risk factors for lower extremity injury in elite ballet dancers to be poor alignment, poor lumbo-pelvic control, reduced strength in the lower extremity, poor cardiorespiratory fitness, and ineffective contraction of transverse abdominis. A decrease in ballet dancers' thigh strength has also been demonstrated to correlate to a greater degree of injury (Koutedakis et al., 1997). Since most injuries in ballet are caused primarily by factors such as poor control, fitness, alignment, and strength, it is plausible that the implementation of additional training can significantly reduce the prevalence of such injuries in ballet dancers.

Strength Training

Benefits of Strength Training

ST, a common form of exercise, provides a variety of health benefits to each population. Previously seen as an activity only beneficial for those such as powerlifters, bodybuilders, or football players, ST has grown in popularity for its benefits seen in men and women alike. In addition to increases in muscular strength, power, and endurance, the general population can experience improved insulin sensitivity, increased resting metabolic rate, improved cardiovascular health, and increased bone mineral density (Westcott, 2012). In a sedentary society where obesity, heart disease, and metabolic diseases have become commonplace, the implementation of ST poses incredible potential to reverse such risk factors for the general population (Westcott, 2012). ST is also a key component of physical fitness for athletes. Athletes can manipulate variables such as intensity, duration, and frequency of ST to elicit different muscular effects (American College of Sports Medicine, 2009). The utilization of this concept in ST to best prevent injury, overtraining, stagnation, and to best prepare an athlete for an athletic performance is known as periodization (Harttman et al., 2015). Athletic populations implement ST into their training regimens due to its many benefits.

Increased Muscle Mass

Perhaps the most obvious beneficial aspect of ST is the increase in muscle mass. As a result of ST, muscles are broken down and then are rebuilt to be stronger, more powerful, and endure a greater amount of resistance. Although research does not support the growth of new muscle fibers as an adaptation of ST, muscle fiber hypertrophy has been identified to occur in skeletal muscle (Potteiger, 2018). ST can be used to produce different responses in skeletal muscle. Athletes can train the muscles to see adaptations more specific to muscle hypertrophy, endurance, strength, or power (Haff & Triplett, 2016). Table 1 displays how the number of sets and repetition, level of intensity, and length of rest between sets influence the type of muscle gains seen.

Table 1

Programming for Different ST Goals

Goal:	Sets	Repetitions	Intensity (%1RM)	Rest
Endurance	2-3	12+	<67%	≤30 sec
Hypertrophy	3-6	6-12	67-85%	30 sec-1.5 min
Power	3-5	3-5	75-85%	2-5 min
Strength	2-6	≤6	>85%	2-5 min

Note: Information in table is derived from Haff and Triplett (2016).

Increased Resting Metabolic Rate

Athletes also experience an increase in resting metabolic rate, the amount of energy the body needs to sustain itself at rest, as a result of ST. Two primary reasons support this increase in metabolic rate: greater muscle mass requires a greater amount of energy for tissue maintenance thus increasing energy needs for sustenance and muscle tissue repair within 72 hours following a ST session requires additional energy to support muscle remodeling (Westcott, 2012).

Improved Cardiovascular Health

ST has also been noted to improve aspects of cardiovascular health. Kelley and Kelley (2000) found that ST can lower resting blood pressure values, and Cornelissen and Fagard (2005) identified that resting blood pressure levels reduce similarly in both ST and aerobic activity. There is conflicting evidence as to whether ST can reduce blood lipid levels, a risk factor for cardiovascular disease. However, research is conclusive that ST, especially coupled with aerobic exercise, improves cardiovascular health and consequently reduces the risk of cardiovascular disease (Braith & Stewart, 2006). Although cardiovascular health is of particular concern in older adults, athletes can experience these same beneficial effects to help improve and preserve their health.

Increased Bone Mineral Density

Due to the high amount of resistance encountered when ST, the body's structures adapt to create a stronger, denser skeleton to support such heavy loads. Layne and Nelson (1999) concluded that ST is directly correlated with higher bone mineral density values in both athletic, young populations as well as older adults. ST can also aid premenopausal women in achieving the greatest bone density possible and aid in the prevention of osteoporosis, a disease common to postmenopausal women (Layne & Nelson, 1999; Martyn-St James & Carroll, 2010). Because of this, ST has been determined to be particularly beneficial to younger females due to its capacity to increase bone mineral density, a trait that typically peaks before the age of 30 in females (Lu et al., 2006).

Improved Mental Health

The physical benefits of ST are plentiful, and these benefits are also impactful to mental health. A comprehensive review by O'Connor et al. (2010) found that strength training was correlated with decreased levels of anxiety and depression, higher self-esteem, and lower levels of fatigue. O'Connor et al. (2010) additionally found lower pain levels experienced by those with low back pain, fibromyalgia, and forms of arthritis. While proper programming can lead to such positive benefits, it should also be noted that overtraining can cause depression-like symptoms, thus reversing the positive effects on mental health (Paluska & Schwenk, 2000)

Increase in Growth Hormone

ST increases the body's hormone levels of testosterone and growth hormone. In both males and healthy females, this increase is present after each session of ST. However, in females with menstrual irregularities, Waters et al. (2001) found that amenorrheic athletes displayed 4-5 times less of a surge of growth hormone following an exercise session when compared with eumenorrheic athletes. Changes in anabolic and ovarian hormones due to ST remain unstudied to date; however, Nakamura et al. (2011) hypothesized that the female athlete's menstrual cycle phase can influence changes in anabolic hormone levels as a result of ST. This is confirmed in a study by Kissow et al. (2022) which determined that the normal fluctuations of estrogen and progesterone throughout the menstrual cycle play a large role in protein metabolism and recovery. Although data is not available regarding the effect of ST on female hormones, data is conclusive that ST leads to a surge of growth hormone and testosterone (Craig et al., 1989; Nakamura et al., 2011).

Weakness of Strength Training

Lack of Cardiorespiratory Endurance

Despite many advantages associated with ST, one key aspect of health-related physical fitness it fails to address is cardiorespiratory endurance. Since traditional forms of ST are comprised of shorter bouts with ample recovery time between sets and repetitions, the cardiorespiratory system is not engaged in a way that would cause positive adaptations. A study by Ignjatovic et al. (2011) tested the effects of ST on cardiorespiratory endurance in young athletes. The researchers found no significant difference in cardiorespiratory endurance following the intervention. Since traditional forms of ST do not lead to a significant increase in cardiorespiratory endurance, it is not sufficient for an individual to focus on ST alone when seeking health-related physical fitness.

Special Considerations for Implementing Strength Training in Ballet

Despite having beneficial aspects, current literature has provided evidence to support that many gaps exist when considering the development of physical fitness in ballet. The most prominent of which include the presence of the female athlete triad, the prevalence of injury, overtraining, and a lack of muscular strength and power. It is clear that dancers need supplementary training in order to develop their athleticism and physical fitness. Having addressed the unique strengths and weaknesses of ballet and ST, there are many factors to address when considering implementing ST into the training regimen of ballet dancers. To date, ballet dancers do not strength train and believe that it would greatly hinder their bodies' aesthetic needed in ballet and lead to oversized, inflexible muscles (Farmer & Brouner, 2021). Therefore, there is great hesitancy when considering implementing ST. Training programs must be tailored to the unique needs of ballet dancers. These special considerations are crucial to the success of strength training in ballet.

Why Strength Training?

Many types of exercise exist that could be used as supplemental training; however, ST poses the greatest potential for mending the gaps present in ballet. This is due to the fact that it addresses the majority of the weaknesses present in ballet and has been well-researched in the literature and proven to be effective.

The Female Athlete Triad

Bone Mineral Density

Through implementing ST into training regimens of female ballet dancers, each aspect of the female athlete triad can be addressed. The first aspect of the triad that ST addresses is bone mineral density. It has been demonstrated that strength training increased bone mineral density in all populations (Layne & Nelson, 1999). Since it is common for ballet dancers to suffer from reduced bone mineral density minimally in the upper extremity and at non-weight bearing sites, female ballet dancers can greatly benefit from the addition of ST as a means of addressing this condition (Koutedakis & Jamurtas, 2004; Wewege & Ward, 2018). Educating female ballet dancers on ST can serve to benefit their long-term health. Koutedakis and Jamurtas (2004) expressed concern as to whether ballet dancers would be able to recover bone mineral density as most is accumulated before the age of 30 (Lu et al. 2016). If dancers are unaware of how to strength train, they will likely reach the age of 30 without building bone mineral density. Failure to build bone mineral density before the age of 30 can affect the rate of bone mineral deterioration throughout life (Lu et al., 2016). Low bone mineral density is of particular concern for females due to the prevalence of osteoporosis after menopause (Lu et al., 2016). Through the addition of ST, female ballet dancers can improve bone mineral density and improve their long-term health.

Disordered Eating

ST addresses the second aspect of the female athlete triad, disordered eating. ST requires a great amount of nutrients which supply and repair the body as it performs strenuous activity. It has been determined that strength athletes require a greater protein intake than endurance athletes in order to repair and sustain muscle tissue (American Dietetic Association et al., 2009). Whereas the Recommended Daily Allowance for protein intake is 0.8 grams/kilogram bodyweight, strength training athletes require a protein intake range of 1.2-1.7 grams/kilogram bodyweight (American Dietetic Association et al., 2009). As dancers are educated about the nutritional needs associated with ST, their caloric intake will likely increase to meet the demands of ST along with classical ballet training. Ultimately, there is likely a correlation between dancer education regarding nutritional needs and a dancer's caloric intake, and these would only be magnified with the incorporation of ST into a dancer's training (Chaikali et al., 2023; Rosenthal et al., 2021). As perceptions change regarding nutrient intake through dancer education, eating habits and views towards food will change for the better in the ballet culture.

Amenorrhea

The third aspect of the female athlete triad is amenorrhea or menstrual dysfunction. Since amenorrhea in young female athletes is often the result of poor hypothalamic function due to excessive training and poor nutrition, an increase in these components can aid young, female dancers in preventing amenorrhea (Huhmann, 2020). ST is an effective means of gaining strength, improving regulation of the HPG axis, and meeting nutritional needs. As ST is implemented, strength is gained, and nutritional needs are being met in ballet dancers, estrogen levels will increase (Huhmann, 2020). The HPG axis will be able to resume its proper function, and the menstrual cycle will begin to regulate.

Power, Strength, and Control

Jumping ability is a key indicator of success and performance ability in ballet dancers (Ávila-Carvalho et al., 2022). There are many movements in ballet that require explosive energy to execute. The ability to quickly reach positions in a controlled and sustained manner improves the aesthetic appearance of the dancer. Similar to power, strength is a necessary component of a successful ballet dancer. Reid (1988) found that ballet dancers only possess 77% of their weight-predicted normal amount of strength. ST can be tailored to target a variety of actions such as endurance, strength, power, or hypertrophy. Through the addition of ST specifically targeting power and strength, dancers can significantly increase their power output and strength capabilities and thus improve their performance abilities (Ávila-Carvalho et al., 2022; Escobar-Álvarez et al., 2022). Ávila-Carvalho et al. (2022) noted that supplementary ST was the determining factor when considering how to improve jump height and power output. Dowse et al. (2020) found that ST intervention caused an increase in power as well as lower extremity strength and dynamic balance. Many ballet movements require the dancer to remain controlled throughout the entire range of motion of each joint in accordance with the aesthetically appealing aspect of ballet (Schmit et al., 2005). This is unique from other sports where such control is not as necessary or desired. These components aid ballet dancers in skill acquisition, control over movement, and overall physical fitness.

Reduced Risk of Common Ballet Injuries

The integration of ST into the training of ballet dancers leads to increased strength, power, dynamic balance, as well as increased stability. Increased stability can benefit dancers greatly since their level of flexibility and range of motion often exceeds that which they are able to control. This aids in dancers' alignment and increase their overall lower body strength, both of which are prominent risk factors for lower-extremity injuries in female ballet dancers (Biernacki et al., 2021). Injury to the first metatarsophalangeal joint, patellofemoral syndrome, compartment syndrome in the shins, and ankle impingement syndrome can all result from poor alignment (Khan et al., 1995; O'Kane & Kadel, 2008). Khan et al. (1995) pointed to proper strength programs, as well as conservative therapies as needed, to ensure proper technique. Many overuse injuries in ballet are caused due to poor alignment when the dancer is in a turned-out position. Inadequate external rotation at the hip joint causes the knee, ankle, and foot joints to compensate, or "roll in", thus causing poor alignment and risk of injury. This kinetic chain dysfunction causes overuse injuries which account for the majority of injuries in ballet dancers (Macintyre & Joy, 2000). The remaining two most common injuries in ballet are stress fractures in the second metatarsal and flexor hallucis longus tendinitis. Stress fractures in the second metatarsal often result from delayed menarche or poor nutrition, aspects related to the female athlete triad that strength training can counteract (O'Malley et al., 1996). Flexor hallucis longus tendinitis often results from the excessive ankle plantarflexion needed for pointe work. This injury is typically treated by strengthening muscle imbalances in order to prevent excessive foot winging or rolling in (Vosseller et al., 2019). If programmed well, ST can reduce risk of these types of injuries due to its muscle building, stabilizing, and injury preventing effects in athletes (Beato et al., 2021). Other risk factors for injury in ballet include poor control and fitness. With increased stability and strength to manage the vast ranges of motion present in ballet dancers, risk of injury is decreased. Additionally, the implementation of ST directly works to improve health-related physical fitness as muscular strength and endurance are two of the five components.

Periodization

Unlike all other sports, ballet dancers lack periodization throughout their training and performing schedules. As a result, overtraining and burn-out are commonplace as well as an increased risk of injury. The focus in ballet must shift from purely skill acquisition to the dancer as an athlete. When ST is implemented as supplementary training for ballet dancers, an element of periodization is introduced. Training can be assessed holistically, and dancers can be prepared to perform optimally (Wyon, 2010). Wyon (2010) advocates for the integration of supplemental training and periodization since the athletic demands of ballet dancers are similar to those of other sports.

Is Strength Training Sufficient?

Cardiorespiratory Endurance

Although ST poses the capability to significantly improve the health and fitness of ballet dancers, there remains one key aspect of physical fitness that remains unaddressed. A prominent weakness of ballet is its failure to improve cardiorespiratory endurance. This cardiorespiratory endurance, although often overlooked, is crucial when considering the high VO_2 demands experienced during elite ballet dancers' performances. Literature has recognized this weakness and often proposes that strength training incorporate endurance elements in order to address the cardiorespiratory health of dancers. One type of training that has been proposed is known as high intensity interval training (HIIT). HIIT is known for its ability to increase both aerobic and anaerobic capacities (Rodrigues-Krause et al., 2015). Because ballet is an intermittent activity with shorter bouts reaching 80-90% of the dancers' VO_2max, HIIT can recreate a similar environment, working at an exercise-rest ratio of 1:1 with 3-to-6-minute bouts of exercise at 90-95% VO_2max (Rodrigues-Krause et al., 2015). Although HIIT logically follows as a method of improving ballet dancers' cardiorespiratory endurance, more research is needed to confirm this hypothesis.

The Concern of Overtraining

Another valid concern when considering the addition of strength training into the training of ballet dancers is the concern of overtraining. Ballet dancers train with a vigorous schedule that is not based on current best practices. They are at increased risk for overtraining and burn-out due to the intensity of their technique class, rehearsal, and performance schedules. They are additionally hyper-focused on skill acquisition and are not focused on ensuring a periodized training regimen. Adding supplemental ST to the current schedule of ballet dancers would likely lead ballet dancers to an overtrained state (Twitchett et al., 2009). Consequently, fitness professionals must consider this and work alongside dance teachers for the good of the ballet dancer as an athlete. Literature has proposed a variety of special considerations to prevent overtraining in ballet dancers when adding supplemental ST. Twitchett et al. (2009) suggested substituting 2 or 3 technique classes per week with an additional strength and conditioning class and noted that this would not lead to deteriorated technique levels. Koutedakis and Jamurtas (2004) noted that any changes or additions to training should be approached cautiously as the aesthetic appearance of dancers should not be altered. Periodization should also be used as a means of combatting overtraining. Similar to other sports, volume of supplemental training should peak when performances are farthest away. As performances near, volume should decrease, particularly when rehearsal time is increased, and intensity should either remain the same or increase (Wyon, 2010). Through the prudent planning and research of a fitness professional, strength training can safely be implemented into the training of ballet dancers without an increased risk of overtraining.

Dispelling Myths Related to Strength Training in Ballet

Although research in ballet is conclusive that the inclusion of supplemental training, namely ST, is beneficial for ballet dancers, the vast majority of female ballet dancers do not include it in their training regimens. This disparity is likely due to the presence of myths regarding ST which are likely spread by older ballet teachers who are unaware of the current literature. Two myths have significantly affected the perception of ST in ballet. The first and likely the most prominent ST myth is that it will make the dancer “bulky”. Since the aesthetic appearance is highly valued in ballet, dancers are unwilling to strength train due to the belief that it will give them oversized muscles. However, Plastino (1990) demonstrated that strength gains can be made without seeing immediate gains in hypertrophy due to neuromuscular effects. Female ballet dancers imagine reaching absolute strength gains similar to males; however, this is not supported in the literature (Roberts et al., 2020). Additionally, with the increase in athletic demands seen in recent choreography, strength is a necessary component to execute such difficult choreography (Farmer & Brouner, 2021). The second ST myth in ballet is the idea that it is not necessary to succeed in ballet. In a study by Farmer and Brouner (2021), ballet teachers were more reluctant to say that ST is essential to ballet dancers’ training. In the same study, ballet dancers reported seeing strength training as an additional form of training, as opposed to essential to their training. However, research has demonstrated that ballet class alone does not elicit adequate physiological adaptations to enhance health-related physical fitness (Koutedakis & Jamurtas, 2004). Education for ballet dancers and teachers alike regarding the literature about optimizing ballet dancers' training can aid in changing perceptions surrounding strength training in the ballet world.

Case Study

When considering how to practically apply ST into the training regimen of a ballet dancer, few studies and reviews have demonstrated practical examples and case studies for fitness professionals to utilize. Through the integration of different guidelines set forth in the literature and an understanding of the principles and movements of ballet, a list of commonly overactive and underactive muscles to target when composing a strength training plan and a sample warm-up incorporating corrective exercises can be formed.

Commonly Overactive and Underactive Muscles

Due to common postural malalignments and tendencies, muscles in the body will tend to be overactive or underactive in accordance with each malalignment (Fahmy, 2021). This seems to be the case in ballet. After personally analyzing common postural malalignments in ballet, there are several muscles that continually appear as either overactive or underactive leading to muscle imbalance. Table 2 offers a cumulative list of lower extremity muscles that may need to be strengthened or inhibited when formulating a ST program based off muscle imbalances noted by Steinberg et al. (2021) and Twitchett et al. (2009). For example, as a compensation for a lack of hip external rotation, the quadricep muscle group, hip flexors, and peroneal muscles will over-activate to make up for the underactivity of the gluteus maximus, gluteus medius, and other deep hip external rotators. Additionally, the adductor muscle group and gastrocnemius-soleus complex over-activate to compensate for the weakened tibialis anterior, tibialis posterior, and hamstring muscle group. Due to the overactivity and underactivity of these muscles, the ankle, knee, and lumbo-pelvic hip complex joints are placed at more vulnerable orientations and are thus more susceptible to injury and hypermobility (Steinberg et al., 2021).

Table 2

Commonly Overactive and Underactive Muscles in Ballet Dancers

Overactive	**Underactive**
Quadricep muscle group (especially rectus femoris)	Gluteus maximus
Gastrocnemius-soleus complex	Gluteus medius
Hip flexors (tensor fasciae latae, iliopsoas, sartorius)	Deep hip external rotators (piriformis, quadratus femoris, etc.)
Adductors	Tibialis anterior and tibialis posterior
Peroneal muscle group	Hamstring muscle group

Note: Information in table is based on Twitchett et al. (2009), Steinburg et al. (2021), and Fahmy (2021)

Implementing a Corrective Exercise-Based Warm-up

Since professional ballet dancers already undergo an intense schedule of rehearsals and classes, a corrective exercise-based warm-up focused on activating underactive muscles and inhibiting and lengthening overactive muscles would be convenient and effective to reduce injury without additional risk of overtraining. The corrective exercise continuum is a tool used by clinicians to correct movement patterns through correcting muscle imbalance in the body. In the corrective exercise continuum, four main steps are utilized to target overactive and underactive muscles (Fahmy, 2021). Firstly, one must inhibit the overactive muscle through myofascial release (Fahmy, 2021). This is commonly done through foam rolling. Next, one must lengthen the overactive muscle through stretching, mostly static and proprioceptive neuromuscular facilitation (PNF) are recommended (Fahmy, 2021). Then, one works to activate the underactive muscle through isolation exercises (Fahmy, 2021). Lastly, this is followed up by integrating the activation of the underactive muscles back into complex, everyday movement patterns (Fahmy, 2021). By targeting the commonly overactive and underactive muscles in ballet dancers before a technique class or rehearsal begins, muscle imbalances can be corrected, and ballet dancers can be better equipped to perform their craft with greater strength and ability. The warm-up displayed in Table 3 can be implemented in conjunction with supplemental strength training sessions, and potentially HIIT, considering the current literature regarding the physiological needs of ballet dancers (Twitchett et al., 2009; Rodrigues-Krause et al., 2015).

Lastly, concerning frequency, it is important to strike the balance between adding enough supplemental training to produce the desired outcomes while preventing an overtrained state. Although not specifically studied to date, the combination of suggestions by Twitchett et al. (2009) as well as traditional ST guidelines outlined by NASM (Fahmy, 2021) would hypothesize that replacing 2-3 technique classes per week with 2-3 additional ST sessions would be sufficient. Since the idea of replacing technique classes altogether may seem unplausible to a professional ballet dancer, an alternative may also be to incorporate more frequent, but shorter bouts of supplemental training in the form of a warm-up as displayed in Table 3, a cool-down, or a separate session completed before or after a more abbreviated technique class. Further research is needed to determine the optimal frequency, intensity, and duration of ST for ballet dancers as well as whether ballet dancers could benefit from a mesocycle of ST during the off-season of summer.

Table 3

A Sample Corrective Exercise-Based Warm-up for Ballet Dancers

Phase	Modality	Muscles Targeted	Training Variables
Inhibit	Self-myofascial release	Quadriceps	~90 seconds per muscle group
		Gastrocnemius-soleus complex	
		Hip flexors	
		Adductors	
		Peroneals	
Lengthen	Static or PNF stretching	Quadriceps	Static stretching: 30-60 seconds, 1-4 reps PNF: 10-6-30 second method
		Gastrocnemius-soleus complex	
		Hip flexors	
		Adductors	
		Peroneals	
Activate	Isolation exercises	Gluteus maximus	4-second eccentric contraction, 2-second isometric contraction at end-range, and 1-second concentric contraction; 10-15 reps
		Gluteus medius	
		Deep hip external rotators	
		Tibialis anterior and tibialis posterior	
		Hamstrings	
Integrate	Dynamic movement exercises	Single-leg balance with multiplanar reach	10-15 reps, controlled movements focusing on technique
		Ball squat to overhead press	
		Single-leg Romanian deadlift to PNF pattern	
		Lateral tube walking	

Note: Information based on Fahmy (2021) and Steinburg et al. (2021)

Conclusion

Recent studies have demonstrated that ballet dancers can benefit greatly from the addition of ST to their training regimen. This is due to specific beneficial qualities associated with ST, such as increased bone mineral density and muscular strength. ST can counteract the weaknesses that often occur in ballet dancers, such as decreased bone mineral density, a lack of periodization, and the risk of the female athlete triad. Since ballet has unique strengths and weaknesses, the implementation of ST, which differs from classical ballet training, can mend the gaps in health and athleticism that arise in ballet dancers. Overall, ballet is an aesthetically beautiful activity and uniquely requires both creative artistry and incredible athletic capabilities. Knowledge of how to implement ST into ballet can benefit future dancers and teachers, and, in turn, positively influence the future of ballet.

References

Allen, N., & Wyon, M. (2008). Dance medicine: artist or athlete? *Sport Exercise Medicine*, *35*.

American College of Sports Medicine (2009). American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Medicine and Science in Sports and Exercise*, 41(3), 687–708. https://doi.org/10.1249/MSS.0b013e3181915670

American Dietetic Association, Dietitians of Canada, American College of Sports Medicine, Rodriguez, N. R., Di Marco, N. M., & Langley, S. (2009). American College of Sports Medicine position stand. Nutrition and athletic performance. *Medicine and Science in Sports and Exercise*, 41(3), 709–731. https://doi.org/10.1249/MSS.0b013e31890eb86

Amorim, T., Wyon, M., Maia, J., Machado, J. C., Marques, F., Metsios, G. S., Flouris, A. D., & Koutedakis, Y. (2015). Prevalence of low bone mineral density in female dancers. *Sports Medicine (Auckland, N.Z.)*, *45*(2), 257–268. https://doi.org/10.1007/s40279-014-0268-5

Arcelus, J., Witcomb, G. L., & Mitchell, A. (2014). Prevalence of eating disorders amongst dancers: a systemic review and meta-analysis. *European Eating Disorders Review : The Journal of the Eating Disorders Association*, *22*(2), 92–101. https://doi.org/10.1002/erv.2271

Ávila-Carvalho, L., Conceição, F., Escobar-Álvarez, J. A., Gondra, B., Leite, I., & Rama, L. (2022). The effect of 16 weeks of lower-limb strength training in jumping performance of ballet dancers. *Frontiers in Physiology*, 12, 774327. https://doi.org/10.3389/fphys.2021.774327

Beato, M., Maroto-Izquierdo, S., Turner, A. N., & Bishop, C. (2021). Implementing strength training strategies for injury prevention in soccer: scientific rationale and methodological recommendations. *International Journal of Sports Physiology and Performance*, 16(3), 456–461. https://doi.org/10.1123/ijspp.2020-0862

Benson, J. E., Geiger, C. J., Eiserman, P. A., & Wardlaw, G. M. (1989). Relationship between nutrient intake, body mass index, menstrual function, and ballet injury. *Journal of the American Dietetic Association*, *89*(1), 58–63.

Biernacki, J., Stracciolini, A., Fraser, J., J. Micheli, L., & Sugimoto, D. (2018). Risk factors for lower-extremity injuries in female ballet dancers. *Clinical Journal of Sport Medicine*, *31*(2), 1. https://doi.org/10.1097/jsm.0000000000000707

Braith, R. W., & Stewart, K. J. (2006). Resistance exercise training: its role in the prevention of cardiovascular disease. *Circulation*, *113*(22), 2642–2650. https://doi.org/10.1161/CIRCULATIONAHA.105.584060

Bronner, S., Ojofeitimi, S., & Spriggs, J. (2003). Occupational musculoskeletal disorders in dancers. *Physical Therapy Reviews*, *8*(2), 57–68. https://doi.org/10.1179/108331903225002416

Brown, K. A., Dewoolkar, A. V., Baker, N., & Dodich, C. (2017). The female athlete triad: special considerations for adolescent female athletes. *Translational Pediatrics*, *6*(3), 144–149. https://doi.org/10.21037/tp.2017.04.04

Bushman, B. (2017). *ACSM's Complete Guide to Fitness & Health* (pp. 1–18). Human Kinetics.

Chaikali, P., Kontele, I., Grammatikopoulou, M. G., Oikonomou, E., Sergentanis, T. N., & Vassilakou, T. (2023). Body composition, eating habits, and disordered eating behaviors among adolescent classical ballet dancers and controls. *Children (Basel, Switzerland)*, *10*(2), 379. https://doi.org/10.3390/children10020379

Cheng, J. C., Chiu, C. Y., & Su, T. J. (2019). Training and evaluation of human cardiorespiratory endurance based on a fuzzy algorithm. *International Journal of Environmental Research and Public Health*, *16*(13), 2390. https://doi.org/10.3390/ijerph16132390

Cornelissen, V. A., & Fagard, R. H. (2005). Effect of resistance training on resting blood pressure: a meta-analysis of randomized controlled trials. *Journal of Hypertension*, *23*(2), 251–259. https://doi.org/10.1097/00004872-200502000-00003

Craig, B. W., Brown, R., & Everhart, J. (1989). Effects of progressive resistance training on growth hormone and testosterone levels in young and elderly subjects. *Mechanisms of Ageing and Development*, *49*(2), 159–169. https://doi.org/10.1016/0047-6374(89)90099-7

Dowse, R. A., McGuigan, M. R., & Harrison, C. (2020). Effects of a resistance training intervention on strength, power, and performance in adolescent dancers. *Journal of Strength and Conditioning Research*, *34*(12), 3446–3453. https://doi.org/10.1519/JSC.0000000000002288

Doyle-Lucas, A. F., Akers, J. D., & Davy, B. M. (2010). Energetic efficiency, menstrual irregularity, and bone mineral density in elite professional female ballet dancers. *Journal of Dance Medicine & Science: Official Publication of the International Association for Dance Medicine & Science*, *14*(4), 146–154.

Escobar-Álvarez, J. A., Jiménez-Reyes, P., Da Conceição, F. A., & Fuentes-García, J. P. (2022). Effect of supplementary physical training on vertical jump height in professional ballet dancers. *International Journal of Sports Physiology and Performance*, *17*(8), 1257–1263. https://doi.org/10.1123/ijspp.2021-0513

Fahmy, R. (Ed.). (2021). *NASM Essentials of Corrective Exercise Training* (2nd ed.). Jones & Bartlett Publishers.

Farmer, C., & Brouner, J. (2021). Perceptions of strength training in dance. *Journal of Dance Medicine & Science : Official Publication of the International Association for Dance Medicine & Science*, 25(3), 160–168. https://doi.org/10.12678/1089-313X.091521a

Gamboa, J. M., Roberts, L. A., Maring, J., & Fergus, A. (2008). Injury patterns in elite preprofessional ballet dancers and the utility of screening programs to identify risk characteristics. *The Journal of Orthopedic and Sports Physical Therapy*, *38*(3), 126–136. https://doi.org/10.2519/jospt.2008.2390

Haff, G., & Triplett, T. (2016). *Essentials of Strength Training and Conditioning* (4th ed.). Human Kinetics.

Hartmann, H., Wirth, K., Keiner, M., Mickel, C., Sander, A., & Szilvas, E. (2015). Short-term periodization models: effects on strength and speed-strength performance. *Sports Medicine* (Auckland, N.Z.), 45(10), 1373–1386. https://doi.org/10.1007/s40279-015-0355-2

Hincapié, C. A., & Cassidy, J. D. (2010). Disordered eating, menstrual disturbances, and low bone mineral density in dancers: a systematic review. *Archives of Physical Medicine and Rehabilitation*, *91*(11), 1777–1789.e1. https://doi.org/10.1016/j.apmr.2010.07.230

Huhmann K. (2020). Menses requires energy: A review of how disordered eating, excessive exercise, and high stress lead to menstrual irregularities. *Clinical Therapeutics*, 42(3), 401–407. https://doi.org/10.1016/j.clinthera.2020.01.016

Ignjatovic, A., Radovanovic, D., Stankovic, R., Marković, Z., & Kocic, J. (2011). Influence of resistance training on cardiorespiratory endurance and muscle power and strength in young athletes. *Acta Physiologica Hungarica*, *98*(3), 305–312. https://doi.org/10.1556/APhysiol.98.2011.3.7

Kalichová, M. (2011). Biomechanical analysis of the basic classical dance jump: the grande jete. *International Journal of Sport and Health Sciences*, *5*(11).

Kelley, G. A., & Kelley, K. S. (2000). Progressive resistance exercise and resting blood pressure: A meta-analysis of randomized controlled trials. *Hypertension (Dallas, Tex.: 1979)*, *35*(3), 838–843. https://doi.org/10.1161/01.hyp.35.3.838

Khan, K., Brown, J., Way, S., Vass, N., Crichton, K., Alexander, R., Baxter, A., Butler, M., & Wark, J. (1995). Overuse injuries in classical ballet. *Sports Medicine (Auckland, N.Z.)*, *19*(5), 341–357. https://doi.org/10.2165/00007256-199519050-00004

Kissow, J., Jacobsen, K. J., Gunnarsson, T. P., Jessen, S., & Hostrup, M. (2022). Effects of follicular and luteal phase-based menstrual cycle resistance training on muscle strength and mass. *Sports Medicine (Auckland, N.Z.)*, *52*(12), 2813–2819. https://doi.org/10.1007/s40279-022-01679-y

Koutedakis. (2000). “Burnout” in dance: the physiological viewpoint. *Journal of Dance Medicine and Science*, *4*(4), 122–127. https://doi.org/10.1177/1089313x0000400402

Koutedakis, Y., & Jamurtas, A. (2004). The dancer as a performing athlete: physiological considerations. *Sports Medicine* (Auckland, N.Z.), *34*(10), 651–661. https://doi.org/10.2165/00007256-200434100-00003

Koutedakis, Y., Khaloula, M., Pacy, P. J., Murphy, M., & Dunbar, G. (1997). Thigh peak torques and lower-body injuries in dancers. *Journal of Dance Medicine & Science*, *1*(1), 12–15. https://doi.org/10.1177/1089313x9700100103

Koutedakis, Y., Myszkewycz, L., Soulas, D., Papapostolou, V., Sullivan, I., & Sharp, N. C. (1999). The effects of rest and subsequent training on selected physiological parameters in professional female classical dancers. *International Journal of Sports Medicine*, *20*(6), 379–383. https://doi.org/10.1055/s-2007-971148

Koutedakis, Y., Pacy, P., Carson, R. E., & Dick, F. (1997). Health and fitness in professional dancers. *Medical Problems of Performing Artists*, *12*(1), 246.

Layne, J. E., & Nelson, M. E. (1999). The effects of progressive resistance training on bone density: a review. *Medicine and Science in Sports and Exercise*, *31*(1), 25–30. https://doi.org/10.1097/00005768-199901000-00006

Lu J, Shin Y, Yen MS, Sun SS. Peak bone mass and patterns of change in total bone mineral density and bone mineral contents from childhood into young adulthood. *Journal of Clinical Densitometry*. 2016 Apr-Jun;19(2):180-91. doi: 10.1016/j.jocd.2014.08.001. Epub 2014 Oct 18. PMID: 25440183; PMCID: PMC4402109.

Macintyre, J., & Joy, E. (2000). Foot and ankle injuries in dance. *Clinics in Sports Medicine*, *19*(2), 351–368. https://doi.org/10.1016/s0278-5919(05)70208-8

Martyn-St James, M., & Carroll, S. (2010). Effects of different impact exercise modalities on bone mineral density in premenopausal women: a meta-analysis. *Journal of Bone and Mineral Metabolism, 28*(3), 251–267. https://doi.org/10.1007/s00774-009-0139-6

McCormack, M., Briggs, J., Hakim, A., & Grahame, R. (2004). Joint laxity and the benign joint hypermobility syndrome in student and professional ballet dancers. *The Journal of Rheumatology*, *31*(1), 173–178.

Nakamura, Y., Aizawa, K., Imai, T., Kono, I., & Mesaki, N. (2011). Hormonal responses to resistance exercise during different menstrual cycle states. *Medicine and Science in Sports and Exercise*, *43*(6), 967–973. https://doi.org/10.1249/MSS.0b013e3182019774

O'Connor, P. J., Herring, M. P., & Caravalho, A. (2010). Mental health benefits of strength training in adults. *American Journal of Lifestyle Medicine*, *4*(5), 377–396. https://doi.org/10.1177/1559827610368771

O'Kane, J. W., & Kadel, N. (2008). Anterior impingement syndrome in dancers. *Current Reviews in Musculoskeletal Medicine*, *1*(1), 12–16. https://doi.org/10.1007/s12178-007-9001-4

Oreb, G., Ruzić, L., Matković, B., Misigoj-Duraković, M., Vlasić, J., & Ciliga, D. (2006). Physical fitness, menstrual cycle disorders and smoking habit in Croatian National Ballet and National Folk Dance Ensembles. *Collegium Antropologicum*, *30*(2), 279–283.

O'Malley, M. J., Hamilton, W. G., Munyak, J., & DeFranco, M. J. (1996). Stress fractures at the base of the second metatarsal in ballet dancers. *Foot & Ankle International*, *17*(2), 89–94. https://doi.org/10.1177/107110079601700206

Paluska, S. A., & Schwenk, T. L. (2000). Physical activity and mental health: current concepts. *Sports Medicine (Auckland, N.Z.), 29*(3), 167–180. https://doi.org/10.2165/00007256-200029030-00003

Phan, K., Nicholson, L. L., Hiller, C. E., & Chan, C. (2020). Prevalence and unique patterns of lower limb hypermobility in elite ballet dancers. *Physical Therapy in Sport*, *41*, 55–63. https://doi.org/10.1016/j.ptsp.2019.11.005

Plastino, J. G. (1990). Incorporating dance science into technique class and performance training. *Journal of Physical Education, Recreation & Dance*, *61*(9), 26–27. https://doi.org/10.1080/07303084.1990.10604622

Potteiger, J. (2018). *Exercise Science: A Systems Approach*. https://www.acsm.org/docs/default-source/publications-files/intro-to-exsci-3_sample-chapter-3.pdf?sfvrsn=2c9320fb_8

Reid, D. C. (1988). Prevention of hip and knee injuries in ballet dancers. *Sports Medicine (Auckland, N.Z.)*, *6*(5), 295–307. https://doi.org/10.2165/00007256-198806050-00005

Roberts, B. M., Nuckols, G., & Krieger, J. W. (2020). Sex differences in resistance training: a systematic review and meta-analysis. *Journal of Strength and Conditioning Research*, *34*(5), 1448–1460. https://doi.org/10.1519/JSC.0000000000003521

Rodrigues-Krause, J., Krause, M., & Reischak-Oliveira, Á. (2015). Cardiorespiratory considerations in dance: from classes to performances. *Journal of Dance Medicine & Science: Official Publication of the International Association for Dance Medicine & Science*, *19*(3), 91–102. https://doi.org/10.12678/1089-313X.19.3.91

Rosenthal, M., McPherson, A. M., Docherty, C. L., & Klossner, J. (2021). Perceptions and utilization of strength training and conditioning in collegiate contemporary and ballet dancers: a qualitative approach. *Medical Problems of Performing Artists*, *36*(2), 78–87. https://doi.org/10.21091/mppa.2021.2012

Schantz, P. G., & Astrand, P. O. (1984). Physiological characteristics of classical ballet. *Medicine and Science in Sports and Exercise*, *16*(5), 472–476. https://doi.org/10.1249/00005768-198410000-00009

Schmit, J. M., Regis, D. I., & Riley, M. A. (2005). Dynamic patterns of postural sway in ballet dancers and track athletes. *Experimental Brain Research*, *163*(3), 370–378. https://doi.org/10.1007/s00221-004-2185-6

Steinberg, N., Tenenbaum, S., Zeev, A., Pantanowitz, M., Waddington, G., Dar, G., & Siev-Ner, I. (2021). Generalized joint hypermobility, scoliosis, patellofemoral pain, and physical abilities in young dancers. *BMC Musculoskeletal Disorders*, *22*(1), 161. https://doi.org/10.1186/s12891-021-04023-z

Stokić, E., Srdić, B., & Barak, O. (2005). Body mass index, body fat mass and the occurrence of amenorrhea in ballet dancers. *Gynecological Endocrinology: The Official Journal of the International Society of Gynecological Endocrinology*, *20*(4), 195–199. https://doi.org/10.1080/09513590400027224

Stracciolini, A., Hanson, E., Kiefer, A. W., Myer, G. D., & Faigenbaum, A. D. (2016). Resistance training for pediatric female dancers. *Journal of Dance Medicine & Science*, *20*(2), 64–71. https://doi.org/10.12678/1089-313x.20.2.64

Twitchett, E. A., Koutedakis, Y., & Wyon, M. A. (2009). Physiological fitness and professional classical ballet performance: a brief review. *Journal of Strength and Conditioning Research*, *23*(9), 2732–2740. https://doi.org/10.1519/JSC.0b013e3181bc1749

Vosseller, J. T., Dennis, E. R., & Bronner, S. (2019). Ankle injuries in dancers. *The Journal of the American Academy of Orthopaedic Surgeons*, *27*(16), 582–589. https://doi.org/10.5435/JAAOS-D-18-00596

Waters, D. L., Qualls, C. R., Dorin, R., Veldhuis, J. D., & Baumgartner, R. N. (2001). Increased pulsatility, process irregularity, and nocturnal trough concentrations of growth hormone in amenorrheic compared to eumenorrheic athletes. *The Journal of Clinical Endocrinology & Metabolism*, *86*(3), 1013–1019. https://doi.org/10.1210/jcem.86.3.7361

Westcott W. L. (2012). Resistance training is medicine: effects of strength training on health. *Current Sports Medicine Reports*, *11*(4), 209–216. https://doi.org/10.1249/JSR.0b013e31825dabb8

Wewege, M. A., & Ward, R. E. (2018). Bone mineral density in pre-professional female ballet dancers: A systematic review and meta-analysis. *Journal of Science and Medicine in Sport*, *21*(8), 783–788. https://doi.org/10.1016/j.jsams.2018.02.006

Wilder, R. P., Greene, J. A., Winters, K. L., Long, W. B., 3rd, Gubler, K., & Edlich, R. F. (2006). Physical fitness assessment: an update. *Journal of Long-Term Effects of Medical Implants*, *16*(2), 193–204. https://doi.org/10.1615/jlongtermeffmedimplants.v16.i2.90

Witkoś, J., & Wróbel, P. (2019). Menstrual disorders in amateur dancers. *BMC Women's Health*, *19*(1), 87. https://doi.org/10.1186/s12905-019-0779-1

Wyon, M. A., Deighan, M. A., Nevill, A. M., Doherty, M., Morrison, S. L., Allen, N., Jobson, S. J., & George, S. (2007). The cardiorespiratory, anthropometric, and performance characteristics of an international/national touring ballet company. *Journal of Strength and Conditioning Research*, *21*(2), 389–393. https://doi.org/10.1519/R-19405.1

Wyon M. (2010). Preparing to perform: periodization and dance. *Journal of Dance Medicine & Science: Official Publication of the International Association for Dance Medicine & Science*, *14*(2), 67–72.

Yau, R. K., Golightly, Y. M., Richardson, D. B., Runfola, C. D., Waller, A. E., & Marshall, S. W. (2017). Potential predictors of injury among pre-professional ballet and contemporary dancers. *Journal of Dance Medicine & Science: Official Publication of the International*

Association for Dance Medicine & Science, *21*(2), 53–63. https://doi.org/10.12678/1089-313X.21.2.53